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MELBOURNE, VICTORIA

Propulsion Technical Memorandum 454

AN APPRAISAL OF A NUMBER OF POWER ASSESSMENT PROCEDURES BEING PROPOSED FOR USE IN CHINOOK-LYCOMING T55 ENGINE

by

D.E. Glenny

Approved for Public Release

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SUMMARY

In response to a request from RAAF HQSC a number of power assessment procedures for application to the Chinook-Lycoming T55 engine have been examined. The most satisfactory procedure was found to be the RAF, Power Assurance Check, (PAC), however because the method has not been fully defined, and its monitoring period is currently set at 25 hour intervals, the procedure will require some refinement before it can be fully utilised. The potentially most attractive procedure is the Power Assurance Test (PAT) proposed in conjunction with the retrofitting of a full authority digital engine control (FADEC) to the T55-L11 engine. This latter procedure has a number of deficiencies associated with it and the RAAF should monitor its development closely before any decision is made to implement the procedures on a regular basis.

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CONTENTS

NOMENCLATURE

A,B,C,D,E.	Constants
N_1	Gas Generator Speed
P	Pressure
PTIT	Power Turbine Inlet Temperature in degree Celsius
PTITK	Power Turbine Inlet Temperature in Kelvin
Q	Torque
T	Temperature
H_p	Pressure Altitude
OAT	Outside Air Temperature
STD	Standard or Reference Condition
SSLS	Standard Sea Level Static
FADEC	Full Authority Digital Engine Control
HIT	Health Indicator Test
PAC	Power Assurance Check
PAT	Power Assurance Test
TEAC	Turbine Engine Analysis Check
TOR	Torque

Suffices

c	Corrected
1	Ambient or Inlet Condition
Margin	margin

Subscripts

AV	Average
CALC	Calculated

1.0 INTRODUCTION

In response to a request from RAAF-HQSC, Reference 1, an appraisal has been carried out on a number of power assessment procedures used or proposed for use on the Chinook-Lycoming T55 engine as operated by the RAAF References 2,3 and 4. Currently the RAAF squadron operating procedures call for a low power level engine check, Health Indicator Test (HIT), to be carried out once per flight just after take-off, and a much higher or topping check to be carried out, on an indicator from the HIT check. Details of the HIT check are given in Reference 5. Basically the HIT check requires the pilot to set the engine up to a given engine speed (N_1) determined by the prevailing outside air temperature (OAT) and to record the indicated power turbine inlet temperature (PTIT). An indicated PTIT of $\pm$ 20°C greater than a predetermined PTIT baseline value is cause for pilot action. The HIT check is usually taken as a GO-NO-GO indicator and the results are not trended from one flight to the next. A major disadvantage of the procedure is that it is carried out at relatively low power levels when engine degradation is difficult to assess, and it only uses a single parameter, temperature, to indicate changes in engine condition or performance. Indicated PTIT margins greater than a prespecified level requires maintenance action and a topping check or maximum power assurance check to be carried out. Topping checks and the accompanying TEAC, Turbine Engine Analysis Check, can be used to reset engine power levels and also to indicate changes in engine torque, gas generator speed and PTIT. Details of these procedures are also given in Reference 5.

The major problem in monitoring engine performance using a combination of daily HIT checks and infrequent TEACs is that the former check is at low power and the latter at the maximum allowable: there is thus a strong case for instituting a power assessment procedure at an intermediate engine power level. That is at a sufficiently high power level that can be used on a regular basis, yet indicate more definitively engine faults, but not at so high a power level that regular use would compromise the life of the engine. This memorandum discusses four such proposals given in References 2, 3 and 4 and gives an appraisal of their respective merits.

2.0 FADEC - Power Assurance Test

Chandler Evans are currently developing a Full Authority Digital Engine Controller (FADEC) for use on Lycoming T55 engines. The FADEC may be included

on an RAAF update of the Chinook-Lycoming T55 in early 1990. The FADEC has a capability through its memory to record and process engine measurands either for immediate display on a cockpit instrument or for retrieval through a data transfer port by maintenance personnel at the end of a flight. The cockpit display can be activated by the pilot, in this mode the FADEC software calculates a PTIT margin defined as

$$\text{PTIT margin} = \text{PTIT}_{CALC} - \text{PTIT}_{AV}$$

where PTIT_{CALC} is derived from the following algorithm

$$\frac{\text{PTIT}_{CALC}}{\Theta AV} = A\ (Q_{AV}/\delta_{AV})^2 + BQ_{AV}\ /\delta_{AV} + C\Theta_{AV} + D\delta_{AV} + E \qquad (1)$$

and A = .00375
B = 2.86725
C = -130.1
D = 29.78
E = 673.6

Q is in % of 1300 ft lb (Torque) and PTIT is in $^{\circ}$C, and δ and θ are ambient correction factors defined as:

$$\delta = \frac{\text{Ambient Pressure (P1)}}{\text{Standard Sea Level Pressure}}$$

$$\Theta = \frac{\text{T1} + 273}{\text{Standard Temperature} + 273}$$

PTIT_{AV}, Q_{AV}, P1_{AV} and T1_{AV} are average values of PTIT, Q, P1 and T1 respectively: the average values are calculated over a period of 3.072 seconds with samples taken every 0.024 seconds, ie. 128 samples. A plot of Equation (1) is given in Figure 1, this line represents the maximum allowable values of PTIT for the engine over its operating range. PTIT margins are defined as the difference between this line and the actual engine steady state operating or running line determined from the averaged PTIT values. In the first instance, it appears that the pilot initiated calculation of the PTIT margin might be independent of engine operating speed or

any variations in individual operating lines. However PTIT versus Torque (power) running lines for RAAF T55-11 engines, taken from work of Reference 6 and given as curves A and B on Figure 1, indicate that the calculation of PTIT margins are a direct function of both the PTIT limit line, Equation 1, and the relative position of the actual (individual) engine steady state operation or running line. It is obvious from the data in Figure 1 that the major problem with this test is the potentially large variation (and possibly erroneous) margins which could occur if the limit line and actual engine operating lines converged (or diverged) at either end of the power spectrum. Calculation of PTIT margins at 40% and 75% Torque for two in-service engines indicates (below) that even though a high margin exists at low powers it is not sustainable at the higher power levels.

	PTIT MARGIN	
TORQUE	**ENG A**	**ENG B**
40%	$38^{o}C$	$57^{o}C$
75%	$-3^{o}C$	$10^{o}C$
Slope Diff.	1.2^{o}/% TOR	1.35^{o}/% TOR

An estimate of PTIT margins at low power should therefore not be extrapolated to high powers. A further problem arises because the actual engine baseline power temperature slopes are not necessarily similar. It is therefore recommended that before implementation of any power assurance procedure, based on PTIT margins as defined in the FADEC software, that a check is made on the "theoretical" algorithm data, and more importantly that the check is carried out at sufficiently high power levels, preferably above 70% Torque.

One undoubted advantage of the FADEC monitoring capability is that it reduces pilot work load in comparison to current manual monitoring procedures. The capability exists with this system to check and record data every flight, hence reducing scatter in trend graphs. If the FADEC system has provision to retain checked data over a significant period of time and the data can be extracted at a later date then a basic automatic engine monitoring, or power assessment procedure can be developed. The extent of the monitoring procedure would depend upon the range of data available from the FADEC memory. Desirable measurands would be N_1, TORQUE, PTIT, δ and θ. Typical analysis procedures using these measurands are given in Reference 6.

3.0 RAF POWER ASSURANCE CHECK

The Power Assurance Check developed by the RAF is a subset of a proposal initially made by Boeing Helicopter Company. The major difference is that while the Boeing check can be undertaken over a range of relatively low power levels, the RAF has defined a given corrected power level to initiate the check, Table 1, and then specified a range of PTITs, Table 2, for that power over a range of ambient conditions. The power level of the RAF check with respect to the FADEC power assurance check is given in Figure 1. Using these data, PTIT margins can be calculated for operations at the same equivalent power. In reality it is a form of high power HIT check. The selected power level is equivalent to an engine torque of 82.8% at SSLS conditions, which is approximately 25% below maximum torque available (10 min operation). During the check the operating envelope for the aircraft is held at nominally 120 KIAS and 100% Rotor RPM, with variations in altitude level controlling the power demand such that TOR/ δ = 82.8%. Data recorded for both engines are annotated onto a Power Assurance Check Proforma, Table 3, and are analysed using Table 2 which gives Check Datum Values; if PTIT is greater than that specified in Table 2, then a full topping check is to be carried out. It is of interest to note that Table 2 gives datum values for both PTIT and N_1, but no instructions are given on use of the N_1 limits. Analysis of the datum check values for PTIT and N_1 indicates that the reference SSLS point (TOR = 82.8, N_1 = 99.05, PTIT = 779.5) has been calculated on the assumption that:

$$N_{1\,SSLS} = \frac{N_1}{\theta^{.4}} = \frac{N_1}{\left(\frac{273 + OAT}{288}\right)^{.4}} \quad , \text{ and}$$

$$(PTIT + 273)_{SSLS} = \frac{PTIT + 273}{\theta^{.86}} = \frac{PTIT + 273}{\left(\frac{273 + OAT}{288}\right)^{.86}}$$

The use of an N_1 margin indicator, simultaneously with the PTIT margin, already calculated, could provide maintenance personnel with a valuable indicator of engine condition. It is noted that the RAF check calls for implementation every 25 hours of flying time; if data from these records are to be trended to give an indication of engine condition, then there will have to be very little scatter in the measurands or

inconclusive results will occur. Previous experience with pilot initiated manual Inflight Monitoring (IFM) procedures (Iroquois) and automatic engine performance monitoring in a Chinook helicopter, References 7 and 6 respectively, indicates that even under the most stable conditions numerous data blocks are required to reduce the effects of data scatter. A power assessment method configured around a proposal to acquire performance records on a 25 hour basis will certainly not provide a reliable and consistent data source for trending nor can it be assumed that it will give a reliable GO-NO-GO indicator of power available. Ideally performance check data should be acquired once per flight under nominally steady state operating conditions and retained for maintenance analysis. Alternate recording periods should only be established after a trial period to ascertain data variability. From experiences in the case of the Chinook-T55 it is highly unlikely that meaningfull trends could be obtained with data records at intervals greater than 5 hours.

A comment should be made here on the Boeing power assessment procedure. This method is more flexible in its application than the RAF procedures described above in that a specific power setting is not required; a range of medium power settings is implied by virtue of the range of operating conditions given in the analysis charts. The increased flexibility of the Boeing test will undoubtedly give rise to increased data scatter, consequently the more restrictive RAF procedure is preferred for power assessment, if only for data repeatability reasons.

4.0 PROPOSED HDH TOPPING AND TEAC CHECKS

These procedures, Reference 2, were developed by HDH in response to an RAAF request to overcome limitations imposed by application of current maximum power topping checks and TEAC. HDH's proposals in summary include:

- minor modifications to the existing topping checks,

- redefinition of TEAC checks to a lower power level, and

- extension of the existing HIT check to include a power (torque) assessment procedure as well as the turbine temperature check.

A brief review of the HDH methods indicates that the proposed procedures, as detailed, are difficult to interpret and may be difficult to implement by the pilot during flight or at the maintenance level.

4.1 Topping Check

No change is envisaged to the intent of this procedure, however minor modifications in procedural aspects are suggested. These include changing the engine setting tolerance from $\pm$ 4% torque to + 4% torque, and the maintenace of a small but + ve torque during power assessment on the engine not being topped. In addition a topping re-check is recommended only when a (new) TEAC analysis indicates a loss in N_1 margin of .8% N_1 or greater.

4.2 (New) Turbine Engine Analysis Check (TEAC)

HDH have completely revised the existing US Army defined TEAC by allowing engine power checks to be carried out over a range of power settings and providing a method for correlating each check to a given reference power level. The power range for the HDH (new) TEAC is given in Figure 1, indicating that it is to be carried out at power levels greater than both the RAF Power Assurance Check and the FADEC check. As the check is so markedly different to previous US Army practice or that matter current RAAF procedures, it would have been prudent and less confusing to have renamed the procedure.

Basically the "new" HDH TEAC is configured around a comparison of actual engine performances with a "theoretical datum engine". The datum engine has the following minimum or degraded performance

$$N_1 = 102\%, \quad \text{PTITK} = 1113, \quad \text{Power} = 3750 \text{ SHP}$$

this is typically .5% N_1 and 1% PTIT below the minimum specification engine which might be released from the test bed.

To en. le a comparison of engine performance to be made with the datum engine values, (under standard day sea level conditions) for TEACs carried out at powers less than 3750 SHP, the following corrections must be made

$$N_1\% \quad = \quad 102 + \frac{1.02}{187.2}\,(SHP - 3750)$$

$$PTIT \quad = \quad 840 + \frac{1}{9}\,(SHP - 3750)$$

Allowances for variations in Sea Level Static (SLS) temperature conditions are made using the following correction factors

$$\frac{N_1}{N_{1STD}} = \Theta^{.5}$$

$$\frac{PTITK}{PTITK_{STD}} = \Theta^{1.022}$$

$$\frac{SHP}{SHP_{STD}} = \Theta^{.587}$$

where $\Theta = (OAT + 273)/288.$

(Variations in pressure altitude have not been included, but can be corrected for by using the following expression

$$\frac{SHP}{SHP_{STD}} = \delta \quad \Theta^{.587}$$

where δ = Ambient Pressure/SSLS Ambient Pressure.

It is of interest to note that the Θ indices used by HDH in correcting the above data, ie. .5, 1.022 and .587 are different to those which have be deduced from the RAF and Boeing defined tests namely .4, .86 and .5 respectively. This discrepancy in values should be identified prior to implementation of any new power assessment check - preferably in consultation with the engine manufacturer.

4.2.1. HDH TEAC Procedures

Two methods for calculating TEAC margins have been given in Reference 2, these are via:

- a programmable calculator, and

- charts and worksheets.

Both methods use the same algorithms but due to rounding off errors a difference in results of up to .3% N_1 and 6^oC PTIT is likely to occur.

The HDH TEAC requires a check to be carried out on initial installation of the engine into the airframe and whenever a power deficit is suspect ie. from a HIT check. The initial installation check establishes baseline values for N_1 and PTIT against which subsequent checks can be monitored. Whilst the power level for carrying out the TEAC is not specified it is recommended (by HDH) that the power level should be within 8% of the equivalent sea level datum of 98% Torque (no inlet screens) or 97% Torque (with inlet screens fitted). This represents a check at a power level of at least 6% Torque (97-8-82.8 = 6.2%) above the equivalent RAF proposed check. The pilot having carried out a normal TEAC its margin or difference from the installed value is assessed using the method given in section 4.8 of Reference 2. It is not proposed to detail the assessment procedures here other than to briefly describe the general philosophy.

Having carried out a baseline TEAC and established reference conditions, recorded data from a normal TEAC are analysed by:

- correcting for ambient conditions - referring data back to Standard Sea Level Static conditions (SSLS),

- correcting data for variations in Rotor RPM; and referring corrected data back to the theoretical datum engine condition mentioned earlier, and

- finally N_1 and PTIT margins for the nominal corrected power output are calculated and trended against a timebase or flight number.

Deviations in the trends from the initially derived margins, or baseline performance, are shown schematically in Figure 2. Deviations of significant magnitude set flags for further maintenance action. Baseline TEAC, and hence baseline PTIT and N_1 margins, are determined from three tests carried out subsequent to engine

installation, however the periodicity for carrying out normal TEACs has not been specified in Reference 2. If it is assumed that normal TEACs are only performed subsequent to a significant deviation in the HIT check then, as with the RAF trend method which relies on data acquired at intervals of 25 hours, the interval between data points will be too large to allow for the inevitable scatter in the manually derived records and the calculated margins. As with the RAF (Power Assurance Check) serious consideration should be given to increasing the frequency at which the HDH TEACs are carried out (assuming that this method is adopted) to enable scatter in the manually acquired measurands to be smoothed out.

4.3 HIT Check - HDH

The HIT check was conceived by McCrory Jr, an Aerospace Engineer with the US Army Aviation Test Board at Fort Rucker. Reference 8 gives details of this procedure which has been applied as a GO-NO-GO indicator, prior to or just after Take-Off, on almost all US Army helicopters. The modifications to the HIT check proposed by HDH in Reference 2 seek to incorporate an additional indicator to progressively monitor the deterioration in engine torque as well as Power Turbine Inlet Temperature. Methods for calculating baseline-expected-torque levels for a specified operating engine speed are given in section 5 of Reference 2, these are derived in a similar manner to those for PTIT. The major difference, is that account must also be made for variations in pressure altitude (Hp) as well as outside air temperature (OAT). A correction factor of +2% to the recorded torque for each 1000 ft above sea level is suggested to give an Equivalent Sea Level Torque. (Note Section 4.2.1 of Reference 2 gives a correction factor of 3% torque per 1000 ft: on the basis of variations of pressure with altitude the latter correction parameter, ie the higher figure, appears to be more appropriate). It is also assumed, in application of the check, that Sea Level Altitude refers specifically to pressure altitude as a function of standard conditions, ie 1013 mb or 29.92 inches of mercury.

A further complicating factor with the re-configured HIT check is that correction factors for changes in Rotor RPM from a reference condition of 235 RPM must be included before a normalised or comparable torque figure can be obtained. From previous experience it is considered that unless some form of automatic recording or calculation procedures are available to the pilot during this modified HIT check then due to high pilot work load the scatter or repeatability of test data could become unacceptable, and the potential usefulness of the extra data would be

lost. The modified HIT procedures whilst technically correct only serve to increase the proliferation of the already numerous engine check procedures.

5.0 RESUME

Engine Power Assurance Procedures from four different sources have been briefly reviewed. With the exception of the FADEC derived PAT, specified by Chandler Evans, the tests rely on manually recorded in-flight data. Experience has shown that especially in helicopter operations it is extremely difficult to obtain consistent stable data to give reliable long term trend results using manual techniques. Two of the other procedures, the new HDH TEAC and the Boeing Power Assurance Check allows data to be obtained over a range of power settings, albeit limited, and then corrects for changes in operating point either graphically or through a set of complex algorithms. Inherent in these correction procedures is the assumption that the slopes of the respective engine running lines are the same: data have been presented that this is not always the case. The major advantage of the proposed RAF and HDH HIT checks is that a constant corrected engine operating point is always chosen for each test, hence eliminating the problems of engine baseline variability. The analysis procedures required by the HDH HIT check are complicated and are carried out under high work load conditions at take-off, the check itself is also carried out at a relatively low engine power setting, N_{1C} = 88.2%. The RAF Power Assurance Check (PAC) which was earlier referred to as a high power HIT check is undertaken at a corrected Sea Level power setting (torque) of 82.8%* once the helicopter is airborne and under controlled transit conditions. However in comparison to the HDH HIT it is only carried out at 25 hour intervals and not on each flight: analysis procedures in the RAF PAC for changes in N_1 from a nominal reference have yet to be defined.

6.0 CONCLUSION

Of the 4 different power check procedures analysed it is clear that the RAF Power Assurance Check is the most satisfactory in an aerothermodynamic and

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* This power setting is similar to the upper level proposed by Boeing and is equivalent to a nominal corrected engine speed of 99.05%: much higher than the HDH HIT check but lower than the proposed HDH TEAC values $100.5 < N_{1C} < 102.5\%$

operational sense, however there is a need to define N_1 reference check limits. The frequency of carrying out the RAF PAC should be increased; checks at 25 hour intervals cannot give consistent data for either long term trending or for that matter a satisfactory GO-NO-GO indicator. The potentially most attractive power assurance tests is that associated with the Chandler Evans FADEC-T55-L712 engine fuel control unit update, provided differences in engine steady state running line characteristics can be resolved. The FADEC PAT becomes even more attractive if the following measurands N_1, TORQUE, PTIT, δ and Θ can be recorded during flight and accessed from the FADEC memory at the end of each flight or series of flights. The FADEC offers the potential for the development of an automatic in-flight data recording system limited only by the ability of the pilot to set up steady state conditions prior to initiating a data recording for cockpit display and retention in the memory buffer. The development of FADEC should be closely followed especially if the RAAF can have an input into the definition of PAT algorithms and their analysis procedures.

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TABLE 1 ENGINE POWER ASSURANCE CHECK TORQUE SETTINGS	
Pressure Altitude (Feet)	Torque Setting (%)
-400	84.0
-200	83.4
0	82.8
200	82.2
400	81.6
600	81.0
800	80.4
1000	79.9
1200	79.3
1400	78.7
1600	78.1
1800	77.6
2000	77.0
2200	76.4
2400	75.9
2600	75.3
2800	74.8
3000	74.2
3200	73.7
3400	73.1
3600	72.6
3800	72.0
4000	71.5
4200	71.0
4400	70.5
4600	69.9
4800	69.4
5000	68.9
6000	66.4
7000	63.9
8000	61.5
9000	59.2
10000	56.9

TABLE 2 ENGINE POWER ASSURANCE CHECK DATUM VALUES		
OAT (^{o}C)	PTIT (^{o}C)	NI (%)
-24	656	93.5
-22	663	93.8
-20	669	94.1
-18	675	94.4
-16	682	94.7
-14	688	95.0
-12	694	95.2
-10	701	95.5
-8	707	95.8
-6	713	96.1
-4	720	96.4
-2	726	96.7
0	732	97.0
2	738	97.3
4	745	97.5
6	751	97.8
8	757	98.1
10	764	98.4
12	770	98.7
14	776	98.9
16	783	99.2
18	789	99.5
20	795	99.8
22	801	100.1
24	808	100.3
26	814	100.6
28	820	100.9
30	826	101.1
32	833	101.4
34	839	101.7
36	845	102.0
38	851	102.2
40	858	102.5

AIRCRAFT NUMBER ____________________

With aircraft in steady state level flight at 125 KIAS, 100% RRPM, engines balanced and with engine anti-icing OFF, record :

	PORT	STBD
ENGINE SER NO.		
GAS GENERATOR SPEED NI		
PRESSURE ALTITUDE FT		
OUTSIDE AIR TEMP. ^{o}C		
ROTOR RPM		
ENGINE TORQUE		
INDICATED AIRSPEED IAS		
POWER TURBINE INLET TEMP PTIT		

Pilot's signature ______________________________

Rank & Name ______________________________

Date ______________________________

Airframe Hours ______________________________

*Certified that *PT/*STBD engines are within limits, the data has been transferred to F711 and that F727 has been updated.

Signature ______________________________

Rank & Name ______________________________

Engine Hours PORT __________ STBD __________

*Certified that Engine Serial No. __________________ is not within limits.

F720B Serial No. ______________ refers.

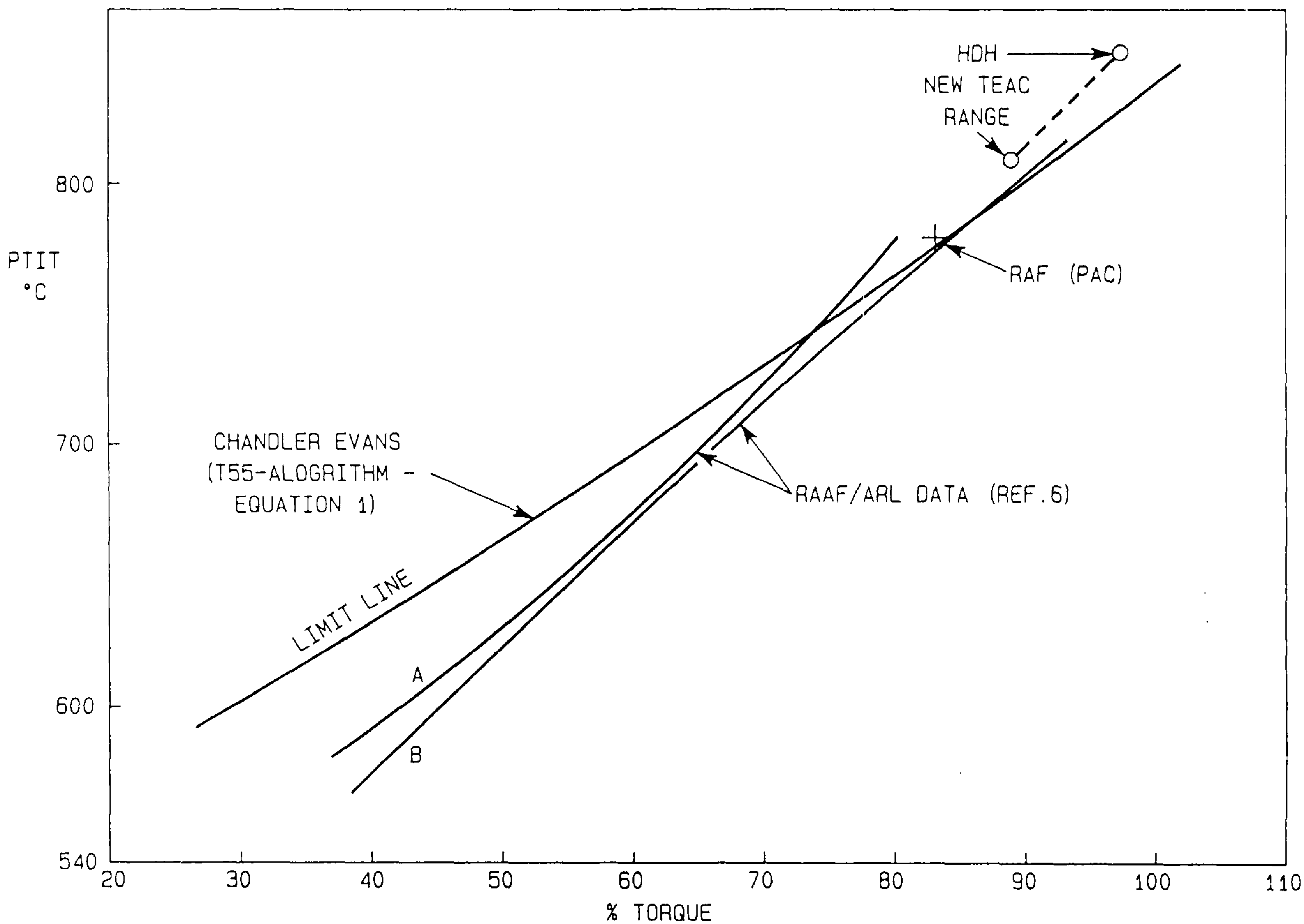
Signature ______________________________

Rank & Name ______________________________

Date ______________________________

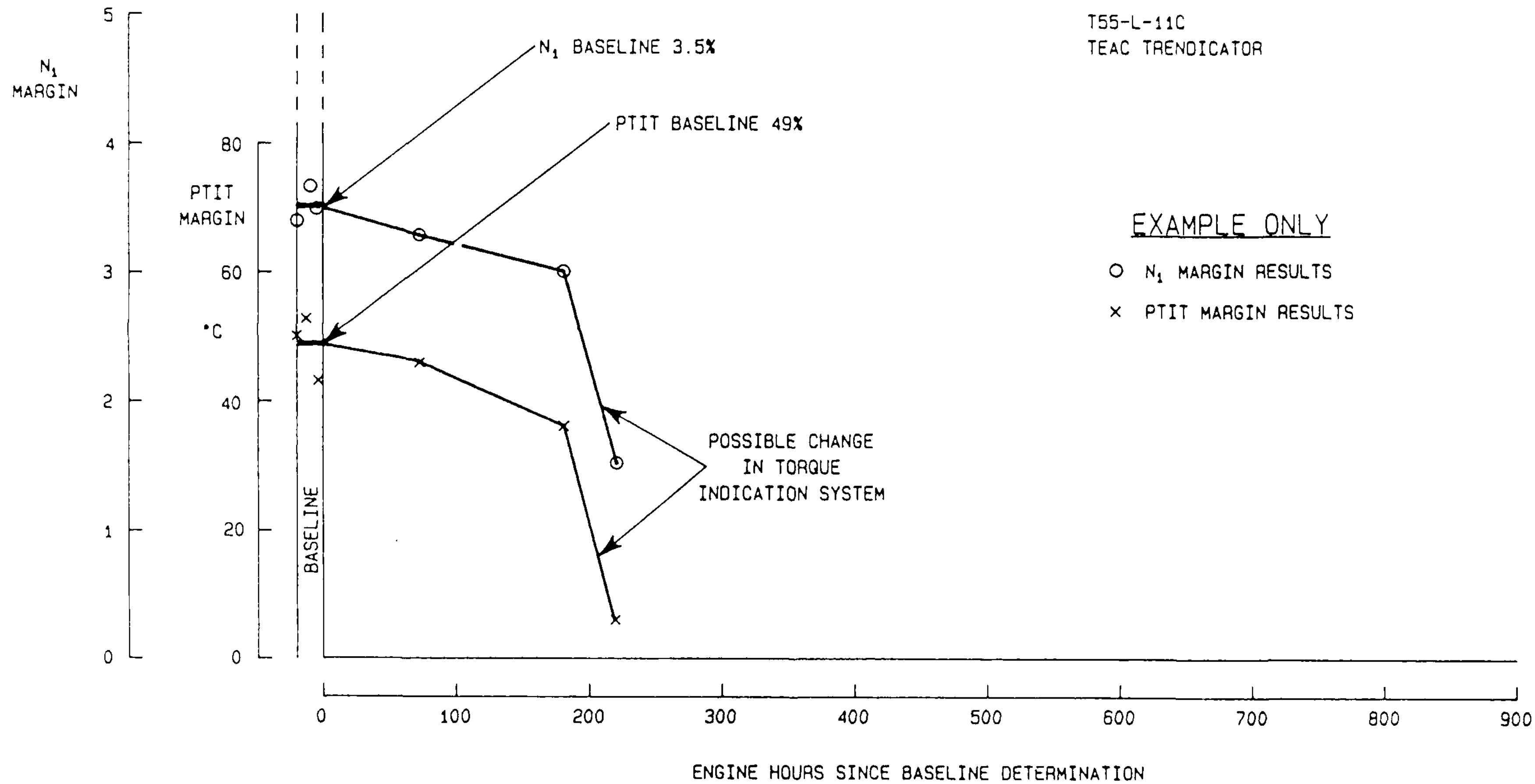
*Delete as necessary.

TABLE 3



HDH
NEW TEAC
RANGE
RAF (PAC)
CHANDLER EVANS
(T55-ALOGRITHM -
EQUATION 1)
RAAF/ARL DATA (REF.6)
LIMIT LINE
A
B
PTIT
°C
800
700
600
540
20
30
40
50
60
70
80
90
100
110
% TORQUE

FIGURE 1



T55-L-11C
TEAC TRENDICATOR
N_1 BASELINE 3.5%
PTIT BASELINE 49%
EXAMPLE ONLY
○ N_1 MARGIN RESULTS
× PTIT MARGIN RESULTS
POSSIBLE CHANGE
IN TORQUE
INDICATION SYSTEM
N_1
MARGIN
PTIT
MARGIN
°C
BASELINE
0
1
2
3
4
5
0
20
40
60
80
0
100
200
300
400
500
600
700
800
900
ENGINE HOURS SINCE BASELINE DETERMINATION

FIGURE 2

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